Automation, Robotics & Communications for Industry 4.0/5.0 (ARCI' 2022):

Proceedings of the 3rd Winter IFSA Conference on Automation, Robotics & Communications for Industry 4.0/5.0

22-24 February 2023

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IFSA Publishing

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Automation, Robotics & Communications for Industry 4.0/5.0
ARCI’ 2023 Conference Proceedings

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ISBN: 978-84-09-47563-6
BN-20230218-XX
BIC: TJFM

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Foreword

On behalf of the ARCI' 2023 Organizing Committee, I introduce with pleasure these proceedings with contributions from the *3rd IFSA Winter Conference on Automation, Robotics & Communications for Industry 4.0 / 5.0(ARCI' 2023)*, 22-24 February 2023.

According to the modern market study the global Industry 4.0. Market size is projected to reach US $ 377.30 Billion by 2029, at a CAGR of 16.3 % during the forecast period, 2022-2029. The Industry 4.0 means the usage of an integrated system, which consists of an automation tool, robotic control and communications. The key factors fuelling the growth of the industry 4.0 market include rapid adoption of Artificial Intelligence (AI) and Internet of Things (IoT) in manufacturing sector, increasing demand for industrial robots, rising government investments in additive manufacturing, and growing adoption of blockchain technology in manufacturing industry.

Industry 4.0 represents the 4th industrial revolution that marks the rising of new digital industry. It is defined as an integrated system that comprises numerous technologies such as advanced robotics control, automation tools, sensors, artificial intelligence, cloud computing, digital fabrication, etc. These technologies help in developing machines that will be self-optimized and self-configured. It helps in enhancing asset performance, technology usage, material usage and other industrial processes that are involves in various industries. Numerous benefits are offered by these technologies such as low operational cost, improved productivity, enhanced customer satisfaction, improved customization, and increased efficiency. The Industry 4.0 holds a lot of potentials and is expected to register a substantial growth in the near future.

The series of annual ARCI Winter IFSA conferences have been launched to fill-in this gap and provide a forum for open discussion of state-of-the-art technologies related to control, automation, robotics and communication - three main components of Industry 4.0. It will be also to discuss how to adopt the current R&D results for Industry 4.0 and to customize products under the conditions of highly flexible (mass-) production, and what we are waiting from the Industry 5.0.

The conference is organized by the International Frequency Sensor Association (IFSA) - one of the major professional, non-profit association serving for sensor industry and academy since 1999, in technical cooperation with media partners – journals: MDPI Processes, MDPI Machines and Soft Measurements and Computing.

The conference proceedings contains all peer reviewed papers, presented at the ARCI' 2023 conference. I hope that these proceedings will give readers an excellent overview of important and diversity topics discussed at the conference.

We thank all authors for submitting their latest works, thus contributing to the excellent technical contents of the Conference. Especially, we would like to thank the individuals and organizations that worked together diligently to make this Conference a success, and to the members of the International Program Committee for the thorough and careful review of the papers. It is important to point out that the great majority of the efforts in organizing the technical program of the Conference came from volunteers.

Prof., Dr. Sergey Y. Yurish,
ARCI' 2023 Conference Chairman

(9246)

Relative Exact Controllability of Fractional Linear Systems with Delays in Control

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Summary: In the paper linear, fractional, continuous time, infinite-dimensional, stationary dynamical control systems with multiple variable point delays in admissible control described by state equations are considered. Using notations, theorems and methods taken directly from functional analysis and linear controllability theory, necessary and sufficient conditions for global relative exact controllability in a given finite time interval are formulated and proved. The main result of the paper is to show, that global relative exact controllability of fractional linear systems with different types of delays in admissible control is equivalent to invertibility of suitably defined relative exact controllability operator. In the proof of main result, methods taken from the theory of linear bounded operators in Hilbert spaces are used. Some remarks and comments on the existing controllability results for linear fractional dynamical system with delays are also presented.

Keywords: Linear control systems, Fractional systems, Delayed systems, Relative controllability, Linear operators.

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1. Introduction

In the paper we shall study global relative controllability in a given finite time interval for fractional, infinite dimensional, linear, continuous time dynamical systems with multiple time variable point delays in admissible controls. This is generalizations of controllability concept, which is known in the theory of finite dimensional linear control systems without delays in state variables or admissible control. Using techniques similar to those presented in the monographs [4, 6], and [10] and in the papers [1] and [3] we shall formulate and prove necessary and sufficient conditions for global relative controllability of fractional systems in a prescribed time interval. It should be pointed out, that the main result of the paper are generalizations for fractional and infinite dimensional delayed systems controllability conditions proved in [1-10].

2. System Description

Let us consider linear, fractional, delay dynamical systems containing multiple lumped time varying delays in admissible controls, described by the following differential state equation with fractional derivative [1, 7, 8]

$$D^{\alpha}x(t) = Ax(t) + \sum_{i=0}^{i=M} B_i(t)u(v_i(t)) \qquad (1)$$

for $0 < \alpha < 1, \quad t \in [t_0 - h, t_1]$.

Initial data $\{x_0, u_{t_0}\}$ forms complete state of the fractional delayed system (1) at initial time t_0.

$$\begin{aligned} &x(t_0) = x_0 \in X, \\ &u(t) = u_{t_0}(t) \ \ for \ \ t \in [t_0 - h, t_0] \end{aligned} \qquad (2)$$

$D^{\alpha}(t)$ denotes fractional Caputo derivative order $0<\alpha<1$. X and U are given Hilbert spaces $x(t) \in X$ is the relative state, A is infinitesimal generator of an analytic semigroup $F(t)$ of uniformly bounded linear operators defined on Hilbert space X. and with resolvent set containing zero.

$B_{i,}$ for i=0,1,2,…,M are given linear bounded operators from U into X. Admissible controls $u \in U_{ad} = L^2([t_0, t_1], U)$.

Initial data $\{x_0, u_{t_0}\}$ forms so called complete state of the fractional delayed system (1) at initial time t_0.

The strictly increasing and twice continuously differentiable functions $v_i(t):[t_0,t_1] \to R$, $i=0,1,2,...,M$, represent deviating arguments in the admissible controls, i.e. $v_i(t)=t-h_i(t)$, where $h_i(t) \geq 0$ are lumped time varying delays for $i=0,1,2,...M$.

Definition 1. [1,8,10]. The system (1) is said to be globally relatively exactly controllable over given time interval $[t_0, t_1]$ if for each pair of vectors $x_0, x_1 \in X$ there exists an admissible control $u \in L^2([t_0, t_1], X)$ such that the solution of (1) with initial conditions (2) satisfies $x(t_1) = x_1$

In order to use results and methods known in the theory of bounded linear operators in Hilbert spaces, let us define linear relative exact controllability operator [10] as follows:

$$C_{\alpha} : L^2([t_0, t_1], U) \to X \qquad (3)$$

$$C_\alpha u =$$
$$= \sum_{i=0}^{i=m} \int_{t_0}^{v_i(t_1)} \sum_{j=0}^{j=m-i} F_\alpha(t_1 - r_j(s)) B_j r'_j(s)) u(s) ds =$$
$$= \sum_{i=0}^{i=m-1} \int_{v_{i+1}(t_1)}^{v_i(t_1)} \sum_{j=0}^{j=m-i-1} F_\alpha(t_1 - r_j(s)) B_j r'_j(s) u(s) ds$$

Using the relative controllability operator C_α and its adjoint operator C_α^* let us define relative exact controllability operator $W_\alpha(t_0,t_1)$ for the linear fractional control system (1) as follows

$$W_\alpha(t_1,t_0) = C_\alpha C_\alpha^* =$$
$$= \sum_{i=0}^{i=m-1} \int_{v_{i+1}(t_1)}^{v_i(t_1)} (\sum_{j=0}^{j=m-i-1} F_\alpha(t_1 - r_j(s)) B_j r'_j(s)) \times$$
$$\times \sum_{j=0}^{j=m-i-1} F_\alpha(t_1 - r_j(s)) B_j r'_j(s))^* ds =$$
$$= \sum_{i=0}^{i=m-1} \int_{v_{i+1}(t_1)}^{v_i(t_1)} (\sum_{j=0}^{j=m-i-1} F_\alpha(t_j - r_i(s)) B_j r'_j(s)) \times$$
$$\times(\sum_{j=0}^{j=m-i-1} B_j^* F_\alpha^*(t_1 - r_j(s)) r'_j(s)) ds$$

Using relative controllability operator it is possible to formulate and prove main result of the paper.

Theorem 1. The following statements are equivalent

(1) Fractional system (1) is globally relatively controllable over $t \in [t_0,t_1]$.

(2) Relative controllability operator $C_\alpha : L^2([t_0,t_1],R^p) \to R^n$ is onto.

(3) Adjoint relative controllability operator $C_\alpha^* : R^n \to L^2([t_0,t_1],R^m)$ is invertible i.e., it is one to one operator.

(4) The bounded linear operator $C_\alpha C_\alpha^* : R^n \to R^n$ is onto and may be realized by *nxn* nonsingular matrix.

4. Conclusion

Using relative controllability operator it is possible to formulate and prove main result of the paper given in theorem 1, which presents necessary and sufficient conditions for global relative controllability in a given time interval. It should be pointed out, that the main result of the paper is the extension for infinite dimensional fractional systems necessary and sufficient conditions for global relative controllability formulated in [1, 3, 8, 10].

Let us observe, that from definition 1 directly follows that the trajectory of dynamical system between initial state, and final state generally is not prescribed. Hence, for globally relatively controllable systems generally there are infinitely many different admissible controls defined on given time interval, which steer dynamical system from initial relative state, to final relative state. Therefore, we may look for admissible control which is optimal in the sense, that it has minimum value of energy (see e.g. monographs [6] and [10]), so, it is so called minimum energy control.

Acknowledgments

The research was founded by Polish National Research Centre under grant "The use of fractional order controllers in congestion control mechanism of Internet", grant number UMO-2017/27/B/ST6/00145.

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